PA197 Secure Network Design
8. Network Monitoring

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Content

Traffic Monitoring—Principles

- Continuously monitor the computer network
- Collect information
- Perform analysis
- Send alerts
- Part of network management
- Wider scope than IDS
  - "natural" causes of network problems
- Traffic monitoring versus service monitoring
  - e.g. status of a particular web server

Why Traffic Monitoring?

- Information about flows in the network
  - to improve Quality of Service
  - to get global view on flows
    - flow between different networks
    - bandwidth optimization for content providers
- Information about applications and frequency of their use
  - to tune network parameters to get better performance
- To group users sharing the same network
- To allow smart logging
  - conforms to the law
  - optimize log files
- To have sufficient data for experiments
  - traffic generators
- To detect malicious traffic

Traffic Classification

- By port
  - applications operating on fixed port numbers
  - simple
  - unreliable
- Deep packet inspection (DPI)
- QoS based
  - rather unreliable
- Statistical classification
  - remember IDS?

Kinds of Tools

- Diagnostic tools
  - usually active
  - connectivity and reachability tests
- Monitoring tools
  - active or passive
  - run “on background”
  - collect events (passive)
  - initiate own probes (active)
- Performance tools
  - flow monitoring

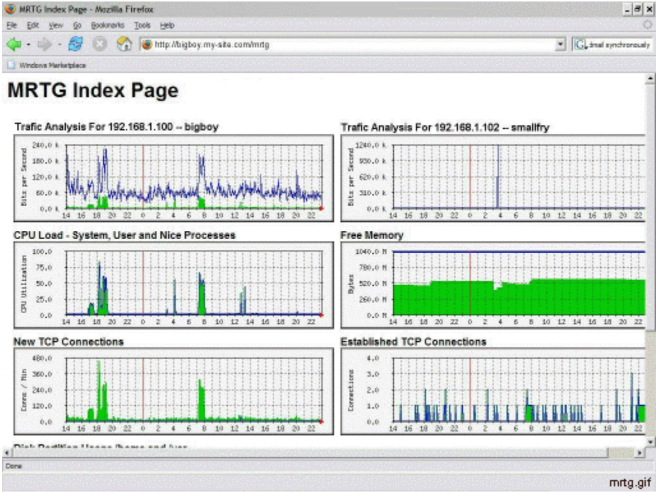
Sample Advanced Tools

- MRTG
- Wireshark
- ntopng
- SolarWinds
- . . .

MRTG

- Multi Router Traffic Grapher
- Free software to monitor and measure traffic load on network links
  - written in Perl
  - available on Linux, OS X. MS Widows, UNIX, ...
- Uses SNMP calls to send requests
  - only SNMP-enabled devices could be monitored
- Creates an HTML document with the list of graphs to display traffic from selected devices

Sample MRTG


MRTG Index Page - Mozilla Firefox
File Edit View Go Bookmarks Tools Help
http://bigboy.my-site.com/mrtg
MRTG Index Page
Trafic Analysis For 192.168.1.100 -- bigboy
Trafic Analysis For 192.168.1.102 -- smallfry
CPU Load - System, User and Nice Processes
Free Memory
New TCP Connections
Established TCP Connections
Done
mrtg.gif

Wireshark

- An open source packet analyzer
  - free software (under GNU GPL)
  - available for Linux, OS X, MS Windows
- Similar to tcpdump, with with extensive GUI
- Understands the structure of many network protocols
  - protocol field parsing
- Uses promiscuous mode on the monitored interface

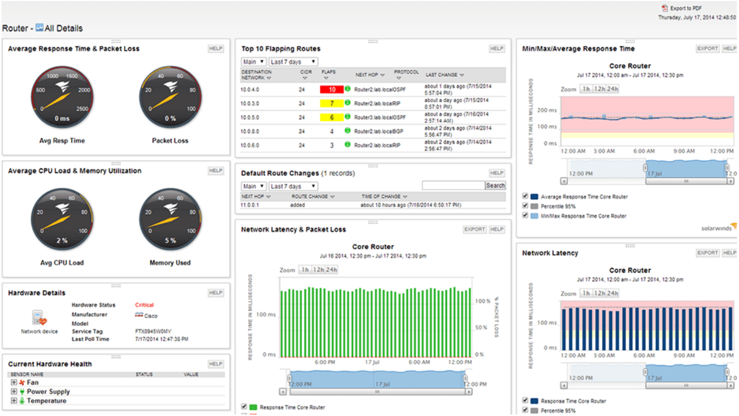
ntopng

- Next generation of ntop
  - see http://www.ntop.org
- Network traffic probe
  - shows network usage in a similar way to the UNIX top command
- Use of web browser interface
  - ntop servers as a web server
- Features (selected)
  - sort network traffic according to the protocols used
  - show IP traffic distribution among various protocols
  - analyze IP traffic and sort it
  - display IP traffic subnet matrix (who is talking with who?)
  - geolocate hosts
  - store traffic statistics in RRD format

SolarWinds

- A commercial product
  - `http://www.solarwinds.com`
- Extensive suite of monitoring tools
  - multi-vendor fault, performance, and availability monitoring
  - dynamic network maps
  - customizable topology and dependency-aware intelligent alerts
  - automated capacity forecasting, alerting, and reporting
  - deep packet inspection and analysis
- Also other products
  - applications and system optimization
  - database performance acceleration
  - security and compliance enhancement

SolarWinds example screen



Netflow Origin and Principles

- Introduced by CISCO
- Available at CISCO routers to collect IP traffic at interfaces
- Analysis of netflow traffic can help
  - to determine source and destination of traffic
  - class of service
  - congestion
- Components
  - flow exporter
    - router: aggregates packets into flow
    - sends them to collector
  - flow collector
    - reception, storage and preprocessing
  - analysis application

Network Flow

- NetFlow version 5
- Flow is a unidirectional sequence of packets that all share the following 7 values:
  1. ingress interface
  2. source IP address
  3. destination IP address
  4. IP protocol
  5. source port for UDP or TCP; 0 for other protocols
  6. destination port for UDP or TCP; type and code for ICMP; 0 for other protocols
  7. IP type of service

  Routing information is not included as it may change during flow lifetime (e.g. due load balancing)
- Also user defined key are allowed in advanced implementations

Sampled NetFlow

- NetFlow designed to process all packets
  - router implementation
- Performance implications for high bandwidth links
- Sampled NetFlow
  - only one packet in *n* is processed
    - deterministic sampling: exactly each *n*-th packet
    - random sampling
  - more complex patterns
    - per flow sampling
  - sampling rate per router or per interface
- Sampling introduces errors
  - INVEA-TECH probes for wire speed at multigigabit networks

IPFIX

- IP Flow Information Export
- IETF protocol
- Standard of export for IP flow information from routers, probes, . . .
- Based on NetFlow version 9
- Defined in the following RFCs: 5103, 7011–7015
- IPFIX flow
  - packets that share same properties observed in a specific timeframe
- Basic Architecture contains
  - metering process collects data at an observation point
  - exporter sends collected flow information to a collector
    - A many-to-many relationship exists between collectors and exporters
  - IPFIX is push protocol

Advantages

- Unobtrusive
  - the attackers can't detect flow monitoring
  - can slow down high traffic bandwidth
    - esp. not sampled monitoring
- Relatively easy to implement
  - information taken from routers
  - probes in the network
- Substantial processing power required
  - for real-time monitoring
  - more extensive analysis possible off-line for limited time periods

Usability

- Observing limits and security policies
  - users' compliance with network use policy
  - service use (for network optimization)
- QoS monitoring
  - passive, but potentially biased
- Traffic accounting

Security related

- P2P network/service detection
- IP port scanning detection
  - TCP RESET packets increase for vertical scan
  - high increase of ICMP Host Unreachable packets for horizontal scan
- DoS attacks detection
  - e.g. TCP SYN-flood attack
  - flash-crowd effect (see later)
- Worms and viruses spread detection
  - high number of unexpected open connections to other computers

Network Behavior Analysis

- Detection of unusual actions through traffic monitoring
- Monitor network inside an organization
  - many monitoring points
  - aggregation
  - trends spotting
    - including e.g. bandwidth fluctuation
- Machine learning methods
  - what is normal behavior?
- Complements IDS, firewalls, ...

Anomaly Detection

- Basic steps
  - uses history of traffic observation to build a model of selected relevant characteristic of network behavior
  - predict these characteristics for the future traffic
  - identify the source of discrepancy between predicted and measured values
- Adaptable, no limit for the detection strength
  - artificial intelligence approach
- Error rate the main potential problem
  - single NBA methods usually prone to high number of false negatives
  - multistage collaborative methods, trust modeling etc. used to overcome this shortcoming

DDoS vs flash crowd

- Web server example
  - highly variable usage patterns
  - unexpected increase in the traffic
    - attack or information attractivity
- DDoS attack
  - malicious activity
  - aim to shutdown the web server
  - distributed access patterns
- Flash crowd (Slashdot effect)
  - massive increase of traffic to a web site
  - due to sudden interest
  - often through linking from a popular site
- Difficult (impossible?) to distinguish

Distinguishing Flash Crowds

- An example taken from the following article
  - Ke Li et al (2009): Distinguishing DDoS Attacks from Flash Crowds using probability Metrics. *Network and System Security NSS'09*, pp. 9–17, DOI 10.1109/NSS.2009.35
- Differences between Flash crowds and DDoS attacks
  - intent: users want content, DDOS wants the site shut down
  - users coming from the whole community network or the whole Internet
    - aggregated source IP addresses resemble flat fractional Gaussian noise distribution
  - DDOS from attackers/botnet
    - aggregated source IP addresses follow Poison distribution
  - difference in traffic increase/decrease
    - users follow the spread wave (gradually increase the traffic)
    - attackers use rather short time frame during the initial phase of attack

The Basic Theory

- Based on a hybrid probabilistic method
  - using similarity between flows to distinguish normal versus flash crowd versus DDoS flows
  - similarity measured as

$$\rho(P, Q) = \sum_{i=1}^{n} \sqrt{p_i q_i}$$

    where $P = (p_1, p_2, \ldots, p_n)$ and $Q = (q_1, q_2, \ldots, q_n)$ are two probability distributions
    $\rho(P, Q) = 1$ for $P = Q$ and $\rho(P, Q) = 0$ when P and Q are
  - total variation calculated as

$$T(P, Q) = \sum i = 1^n |p_i - q_i|$$

The Algorithm

- The algorithm (applied at the last router preceding the server)
  - set grouping thresholds GT_S (similarity) and GT_T (variance); each threshold has an lower and upper bound
  - calculate probabilistic distribution for each aggregated flow
  - calculate total variation $T(P, Q)$ and similarity $\rho(P, Q)$ for each two flows
  - if $T > \mathrm{upper}(GT_T)$ and $\rho < \mathrm{lower}(GT_S)$ the DDoS is detected from Flash crowds
  - if $\mathrm{lower}(GT_T) \leq T \leq \mathrm{upper}(GT_T)$ and $\mathrm{lower}(GT_S) \leq \rho \leq \mathrm{upper}(GT_S)$ then DDoS is detected from Normal flow
  - if $T \leq \mathrm{upper}(GT_T)$ and $\rho > \mathrm{lower}(GT_S)$ than Flash crowds is detected form Normal flow
  - otherwise Normal flow is assumed
  - The values for upper and lower band of thresholds GT_T and GT_S was derived from simulations and are $(0, 5921, 1.1045)$ and $(0.7220, 0.8708)$, resp.

A different method

- Based on article
  - P.R.Reddy et al (2013): Techniques to Differentiate DDoS Attacks from Flash Crowd. Int. J. Adv. Res. Comp. Sci. Soft. Eng., Vol 3(6), pp. 295–299.
- Uses flow correlation coefficient
- Similar observations as above
  - individual attack flows show an internal similarity—flow standard deviation is usually smaller than that of genuine flash crowd flows
  - smaller number of botnet nodes compared to number of genuine flash crowd users
  - each botnet node must initiate higher number of attack flows to mimics the expected number of users

Metrics used

- Flow correlation coefficient
- Packet arrival patterns
- Information distance
- In all cases, the differentiation is based on smaller variance in DDoS attack flows
  - the correlation coefficient use experimentally verified as the most promising metrics

Summary

- Traffic monitoring as a very strong mechanism
    - unobtrusive
    - not detectable by attacker
- Usable in a large range of scenarios
    - performance as well as security related
- Support from network elements needed
    - probes
    - router implementation
- NetFlow and IPFIX
- Network behavior analysis
    - example of DDoS versus Flash crowd detection
- Next session: Wireless Networks (introduction)